

Crop Productivity and Surface Soil Properties of a Severely Wind-Eroded Soil.

T. M. ZOBECK* and J. D. BILBRO, USDA-ARS
Lubbock and Big Spring, TX.

Dr. Ted M. Zobeck *
Wind Erosion and Water Conservation Research
USDA-ARS
3810 4th St.
Lubbock, TX 79415
tzobeck@lbk.ars.usda.gov

Abstract

Wind erosion degrades soil quality by modifying soil properties important for optimum plant growth and productivity. In this study we evaluated soil properties and plant productivity of an Amarillo fine sandy loam soil that had been severely wind-eroded for 9 years, causing a loss of about 10 cm (over 1300 mt ha⁻¹) of the soil surface. Cotton, kenaf, and grain and forage sorghum were grown for two years and soil tests were performed on eroded, deposited, and non-eroded areas. The eroded areas produced 34 percent lower cotton boll weights and 40 percent lower lint weights than the non-eroded areas in 1998. Cotton lint yields were not significantly different ($P < 0.10$) in 1997, probably due to severe insect damage. The grain yield of grain sorghum was an average (over the 2 years) of about 57.5 lower in the eroded area than the non-eroded area. The forage sorghum grain yield in 1998 was 83 percent lower on the eroded area than the non-eroded area. The kenaf yield was an average of about 40 percent lower on the eroded area than the non-eroded area. Erosion had significantly increased ($P < 0.05$) sand content on the deposited area but caused little textural change in the surface of the eroded area compared with the adjacent non-eroded site. The eroded area had significantly less phosphorus, as measured by Bray P1 and P2 methods, than the adjacent non-eroded area. Few differences were found for other plant nutrients among the sites.

Introduction

There is a considerable body of research on the effects of erosion on soil properties and productivity (Follett and Stewart, 1985; Lal, 1988; Larson, et al., 1990; McCool, et al., 1984). However, most of the research focuses on the effects of water erosion and not wind erosion. Usually, indirect methods are used to assess the effect of wind erosion on soil properties and productivity. For example, the effects of wind erosion on soil productivity has been associated with yield data (Fryrear, 1981; Eck et al., 1965), rainfall records (Burnett and Moldenhauer, 1957), or estimates of wind erosion (Lyles, 1975) in areas prone to wind erosion. Direct estimates of the effects of erosion on soil properties have been made using comparisons of the properties of dust and *ex situ* bulk surface soil in the laboratory (Hagen and Lyles, 1985) or in the field (Zobeck and Fryrear, 1986a and 1986b; Zobeck, et al., 1989).

Recent studies of wind erosion used in the development of the Revised Wind Erosion Equation (Fryrear, et al., 1998) and validation of the Wind Erosion Prediction System (Hagen, 1991) have used a unique experimental design consisting of a circular erodible field surrounded by a non-erodible field (Fryrear, et al., 1991). This design allows for the direct comparison of an area with a known amount of wind erosion with a nearby non-eroded soil. Detailed study of such a site eroded for two years in Alberta has been used to determine the effects of limited wind erosion on yields of spring wheat (*Triticum aestivum* L.) and canola (*Brassica napus* L.). Changes in productivity on the eroded area due to wind erosion were reflected in wheat yields but not in canola yields (Larney et al., 1998). However, canola yields were slightly higher in the area where saltating soil was deposited than in the eroded field.

A similar site was established at the USDA, Agricultural Research Service, Wind Erosion and Water Conservation Research Unit field station located in Big Spring, Texas in 1988. The site was eroded for nine years and experienced a total soil loss of 1324 mt ha⁻¹ (591 t ac⁻¹) (D. W. Fryrear, personal communication). This site provided a unique opportunity to study the effects of severe wind erosion on a sandy soil in the southern High Plains. The objectives of this preliminary two-year study were to quantify the effects of wind erosion on the productivity of several crops grown in the region and evaluate the effects of erosion on surface soil texture and nutrient content.

Methods

The study area was located in the southern Great Plains of west Texas at the USDA-ARS Wind Erosion and Water Conservation Research Unit field station in Big Spring, Texas. The climate is semiarid with a mean annual temperature of 17.1°C and mean annual precipitation of 470 mm. The study was conducted on an Amarillo fine sandy loam classified according to Keys to Soil Taxonomy (Soil Survey Staff, 1998) as a fine-loamy, mixed, thermic, superactive Aridic Paleustalf.

The field had previously undergone severe wind erosion as part of a nine-year erosion study. In this wind erosion study, a 3-hectare circular field was maintained in a bare, flat, erodible condition. The field was surrounded by ten ridges approximately 0.3 m high and one meter apart. These ridges trapped saltating soil particles coming from the eroding field. The area where the soil particles were trapped is called the deposited area in this paper. The soil immediately adjacent to the deposited area was maintained in a non-erodible condition and is called the non-eroded area in this paper. A detailed description of the erosion study design and the methods for measuring wind erosion were described by Fryrear et al. (1991).

Four crops were grown on this site in 1997 and 1998. The crops included cotton (*Gossypium hirsutum* L.), grain sorghum [*Sorghum bicolor* (L.) Moench], forage sorghum [*Sorghum bicolor* (L.) Moench], and kenaf (*Hibiscus cannabinus* L.). The crops were planted in 4 blocks (replications) that extended across the three test areas (eroded, non-eroded and deposited) as illustrated in Fig 1. Each block included randomly assigned plots of each crop planted in two sets of 4 rows, separated by one blank row. The row spacing for all crops was one meter. At the end of each crop year in 1997 and 1998, a 3 meter long area was harvested in one of the interior two rows of each crop in each replication. Grain and total dry matter yield were measured for the grain and forage sorghum. Grain was threshed by hand. Total air-dry boll and ginned lint weight were measured in the cotton. Bolls were hand collected and ginned in a small cotton gin. Total dry matter was measured for the kenaf after leaves were removed in the field.

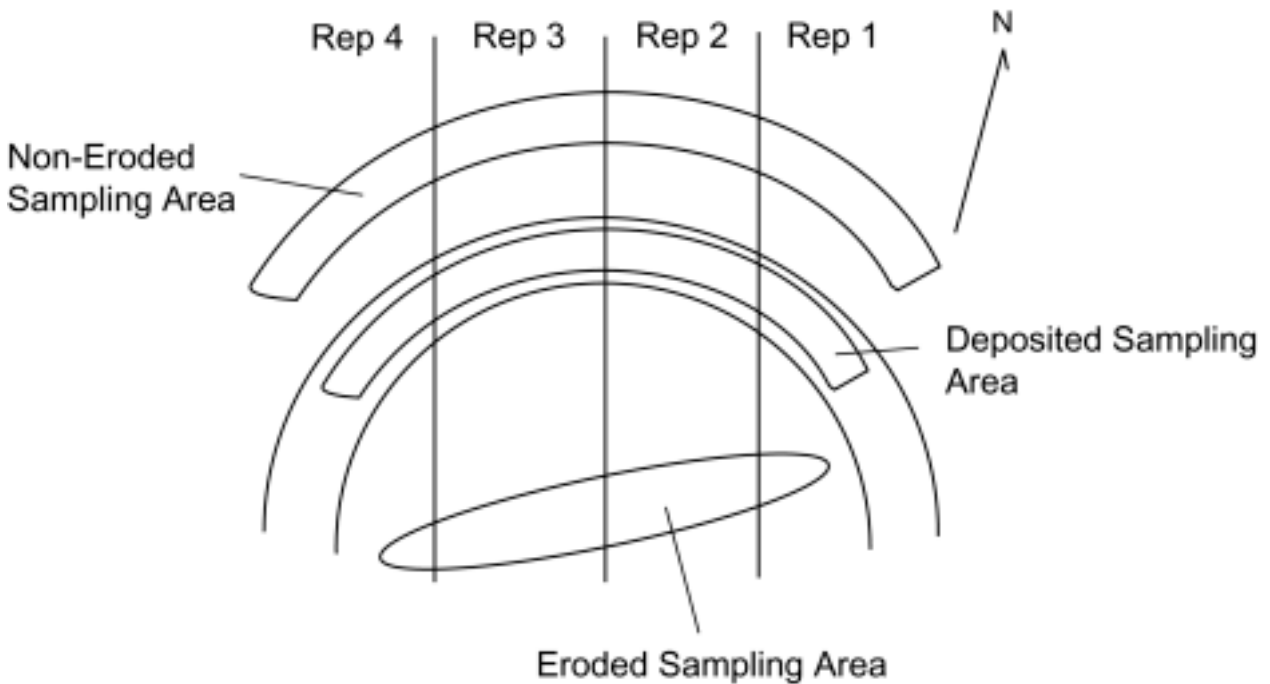


Figure 1. Schematic view of study area. Each rep had cotton, grain sorghum, forage sorghum, and kenaf plots.

Three replications were used in 1997, with the exception of the cotton plants. We experienced problems with boll weevils in 1997 and one of the cotton plots were abandoned due to severe infestation. We eliminated the insect problem with proper application of pesticides in 1998 and added another replication. Thus four replications were evaluated for all crops in 1998.

Soil samples were collected from the upper 15 centimeters in each plot to determine the soil texture and nutrient content. The hydrometer method was used to determine the clay content and sieving was used for the sand content. Silt was determined by difference. Nutrient analyses were performed by A & L Plains Agricultural Laboratories, Inc.¹ in Lubbock, Texas. The soil pH was determined in a 1:1 soil:water solution using a platinum electrode. Organic matter was determined using dichromate oxidation (Nelson and Sommers, 1982). Cation exchange capacity was¹

¹ Use of trade, firm, or corporate names is for information and convenience of the reader. Such use does not constitute an official endorsement or approval by the USDA, Agricultural Research Service of any product or service to the exclusion of others that may be suitable.

Table 1. Number of plants sampled in 3 m plot by crop.

		Mean Number of Plants ^H			Mean
		Deposited	Non-Eroded	Eroded	
Cotton	1997	47.5	45	48.5	47.0
	1998	10.8	13.8	13.25	12.6
Grain Sorghum	1997	40.3	41.7	45.3	42.4
	1998	14	13.5	15	14.2
Forage Sorghum	1997	85.7	69	85	79.9
	1998	15.8	16.3	18	16.7
Kenaf	1997	66.7	71	69.7	69.1
	1998	28.5	32.3	34	31.6

^H Two replications were sampled for cotton in 1997, three reps were sampled for other crops in 1997, and 4 reps were used for all crops in 1998.

determined as the sum of exchangeable cations extracted with ammonium acetate (Thomas, 1982) and measured by atomic absorption. Exchangeable cations measured included Mg, K, and CA. Phosphorus was measured using the weak Bray P1 (Bray and Kurtz, 1945) and strong Bray P2 (NDSU, 1980) methods. Zinc was extracted with DPTA and measured using atomic absorption (Baker and Amacher, 1982). Nitrate was extracted with aluminum sulphate and measured using a nitrate specific ion electrode (Dahnke, 1971).

Analysis of variance for each test variable was performed as a randomized complete block design using SAS version 6 (SAS, 1990). Analyses were performed using $P < 0.10$ for tests of crop yields and $P < 0.05$ for tests of soil texture and nutrient content.

Results and Discussion

Since this study was performed under dryland conditions, rainfall amount and distribution played an important role in shaping the results. Rainfall for both years of this study was below the long-term mean rainfall of 470 mm. A total of 406 mm of precipitation was recorded in 1997 and 337 mm in 1998 (Fig. 2). The rainfall during planting was more abundant in 1997 than that in 1998, resulting in greater plant germination and higher plant populations in 1997 than in 1998 (Table 1). Conversely, there was more rainfall in July and August in 1998 than in 1997.

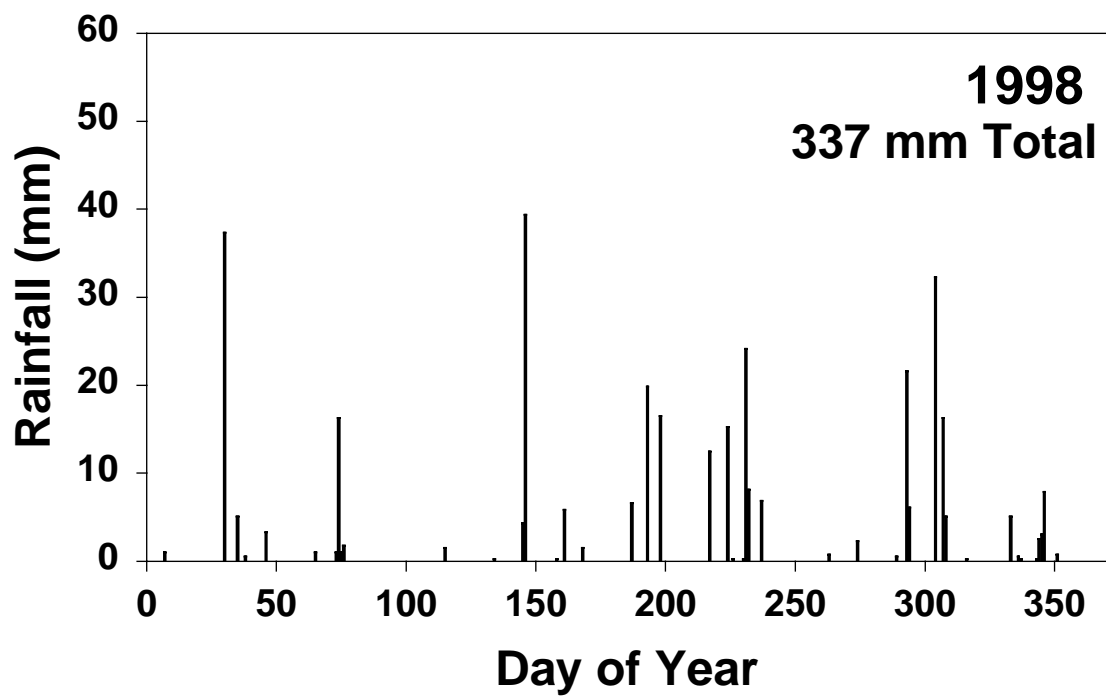
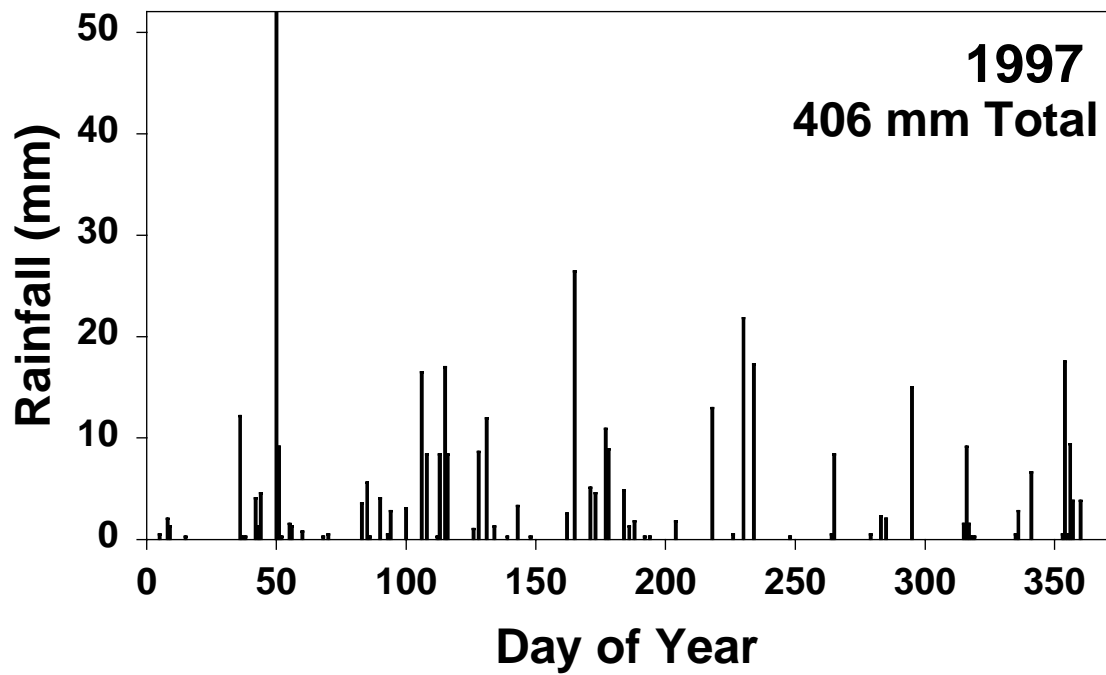


Figure 2. Precipitation of the study area for 1997 and 1998.

Crop Yields

Cotton boll and lint weights were generally lower in 1997 than in 1998, even though the plant populations were considerably higher in 1997 than in 1998 (Fig 3). The difference in yields among years may have been due to differences in rainfall distribution or pests. Although we eliminated 2 cotton plots due to weevil infestation in 1997, the plots remaining may have also been somewhat affected. We did not evaluate the effect of boll weevils on the remaining plots. In addition, the July and August rainfall of 1998 may also been important in significantly increasing the yields of the few bolls that were available. These questions will be explored more fully in future analyses of the data. Cotton boll and lint weights were always greater ($P < 0.10$) on the

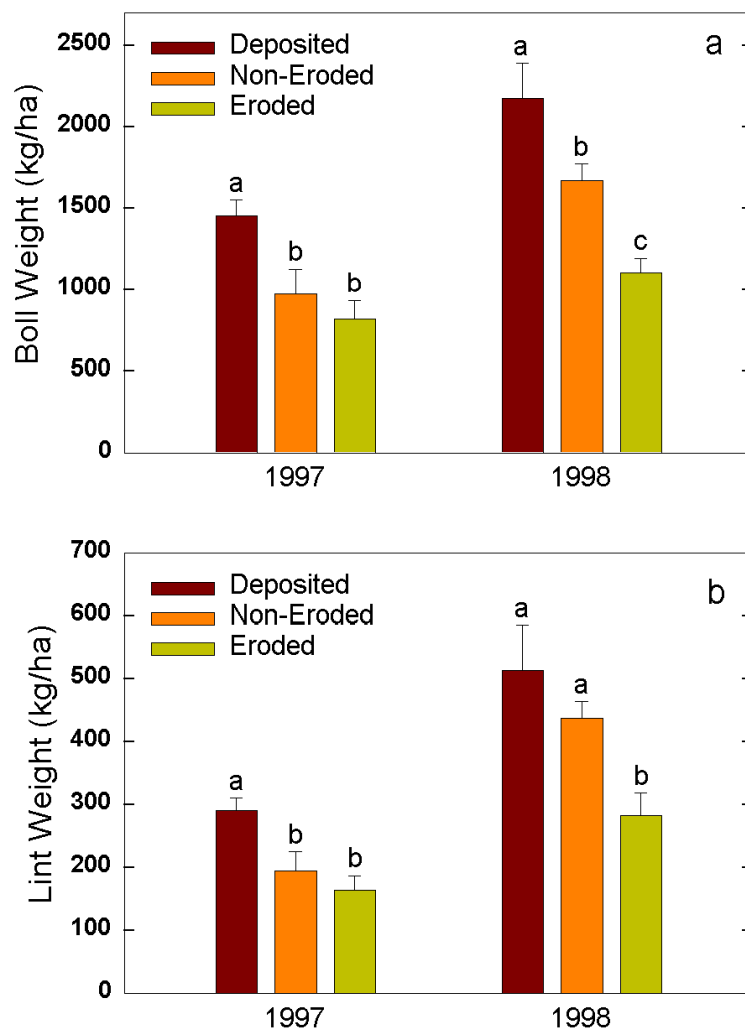


Figure 3. Cotton boll and lint weight, by area, for 1997 and 1998.

deposited sites than the eroded sites (Fig 3). There were no statistical differences in cotton yields between the non-eroded and eroded areas in 1997. However, the eroded areas produced 34 percent lower cotton boll weights and 40 percent lower lint weights than the non-eroded areas in 1998.

Grain sorghum and forage sorghum produced similar results, with the exception that no significant differences in yields were found in forage sorghum in 1997 (Fig 4). In every comparison, the deposited and non-eroded areas produced similar yields that were significantly greater than the yields of the eroded areas. The grain yield of grain

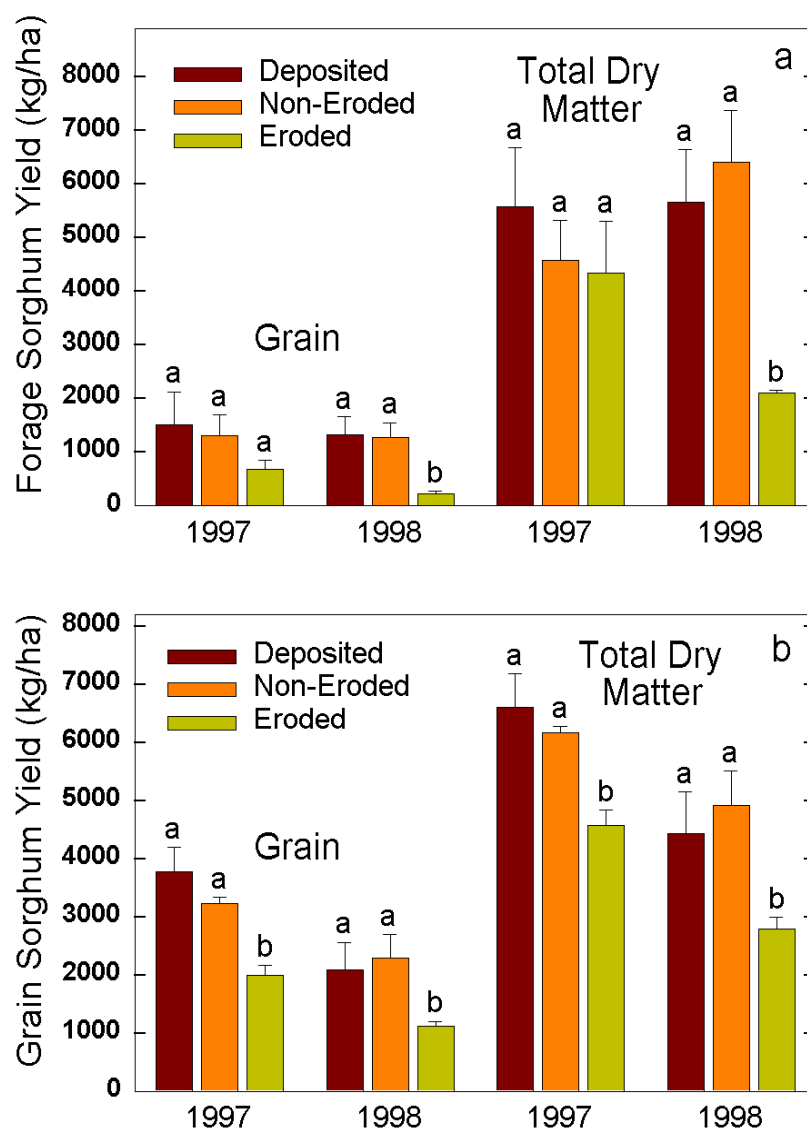


Figure 4. Forage and grain sorghum yields, by area, for 1997 and 1998.

sorghum was an average (over the 2 years) of about 57.5 percent lower in the eroded area than in the non-eroded area. The forage sorghum grain yield in 1998 was 83 percent lower in the eroded area than the non-eroded area. The effect of erosion had similar results on total dry matter (TDM) production of grain and forage sorghum. The eroded area had an average of 34 percent lower total TDM for grain sorghum and 65 percent lower TDM for forage sorghum than the non-eroded area in 1998.

The kenaf yields (stem weights) were much greater in 1997 than 1998 (Fig 5). The reason is not certain, but we believe the greater plant populations in 1997 (Table 1) were able to take advantage of the greater moisture in 1997 than in 1998. The other crops did not show this trend. In 1997 the kenaf yields were in the order: deposited > non-eroded > eroded. The yield of the deposited area was the same as that of the non-eroded area in 1998. The kenaf yield was an average of about 40 percent lower on the eroded area than the other areas.

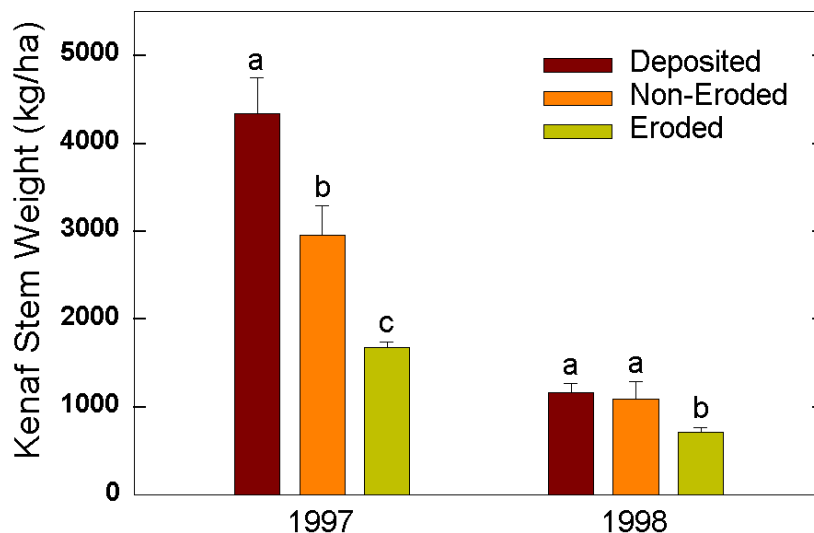


Figure 5. Kenaf yields, by area, for 1997 and 1998.

Soil Properties

Particle size analyses of the surface soil showed no differences in the particle size distribution and resulting texture between the eroded and non-eroded areas ($P < 0.05$, Fig 6a). The deposited area was similar to the non-eroded area with the exception that it contained greater total sand and very fine sand. The difference was great enough to cause the deposited area to be classified as a loamy sand and the other areas as fine sandy loams (Soil Survey Division Staff, 1993).

The nutrient variables that produced significant differences among areas are shown in Fig 6b. No significant differences among areas were observed for organic matter, pH, nitrate, Zn and exchangeable K, Mg, and Ca. Of all nutrients tested, only the phosphorus, as measured by the Bray P1 and P2 methods, had significantly lower

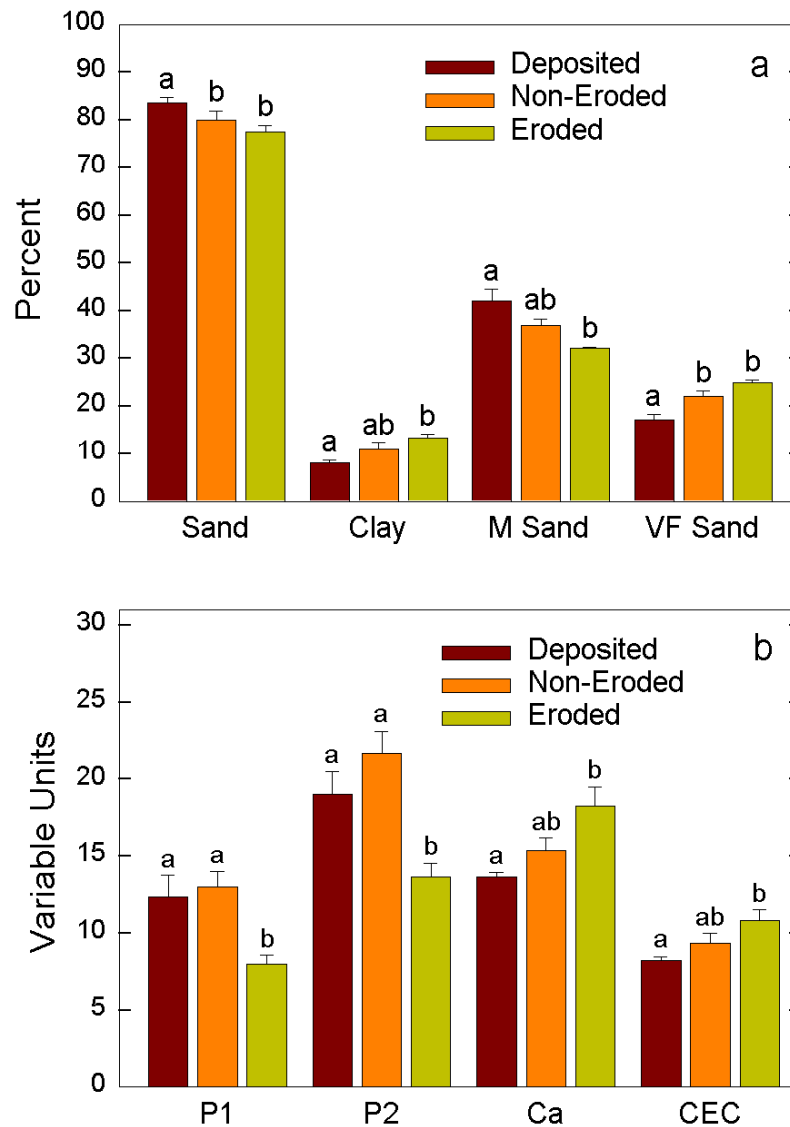


Figure 6. Soil texture (a) and nutrient content (b), by area, for 1997 and 1998.

levels in the eroded areas than in the non-eroded areas (Fig 6b). There were also no significant differences between the deposited and non-eroded areas for any nutrients tested.

The overall effect of the 1324 mt ha^{-1} (132.4 kg m^{-2}) soil loss on soil properties was not dramatic. The minimal effect of erosion on soil texture observed in this study has a simple explanation. Prior to the erosion study, this area was under cultivation for at least 50 years and had developed a rather thick plow layer. Preliminary transects of each area suggest the plow layer of the non-eroded area was about 41.6 cm thick.

Assuming a bulk density of 1.3 Mg m^{-3} (1300 kg m^{-3}), the eroded soil represents an average soil loss of about 10 cm. Removal of 10 cm from the surface of the eroded soil still leaves about 30 cm of fine sandy loam surface soil above the heavier sandy clay loam subsoil, suggesting little mixing of the subsoil into the plow layer. However, the deposited area was made sandier by the deposition of sandy saltating sediment upon the surface that was subsequently mixed into the surface during tillage.

It is unclear why apparently only phosphorus was removed by wind erosion. It is possible that the phosphorus was bound to soil particles found very near the soil surface while the other nutrients were more evenly distributed throughout the plow layer. More detailed studies of this phenomenon are planned.

Conclusions

In this preliminary study, productivity of dryland cotton, grain sorghum, forage sorghum, and kenaf was measured in 1997 and 1998 on a field that had been severely wind eroded, on an adjacent area where saltating particles were deposited, and on an adjacent non-eroded soil. In most cases, with the exception of forage sorghum and cotton yields in 1997, the severely eroded soil produced lower yields than the non-eroded soil. The amount of reduction in yield varied with crop and specific yield parameters but ranged from an average reduction of 28 percent for grain sorghum total dry matter in 1997 to an 83 percent reduction in forage sorghum grain yield in 1998. Yield differences between years was attributed to differences in rainfall amount and distribution as well as insect pressure.

The effect of erosion on soil properties was not as dramatic as that observed for crop yields. There were no significant differences ($P < 0.05$) in soil texture or amounts of particles in individual particle size classes among the eroded and non-eroded areas. The deposited area did accumulate enough sand to be classified as a loamy sand. The non-eroded area was a fine sandy loam. Very few differences in nutrients were observed between the eroded and non-eroded areas. Only phosphorus as measured by the Bray P1 and P2 method was significantly lower on the eroded area than on the non-eroded area. Future studies are needed to further define and evaluate differences among areas in other soil properties, such as soil porosity and water holding capacity differences with depth.

Acknowledgements

The authors gratefully acknowledge the assistance of Ace Berry, Charles Yates, and Dean Holder in the field and lab data collection and processing.

References

- Baker, D. E. and M. C. Amacher. 1982. Nickel, copper, zinc, and cadmium. *In* A. L. Page et. al., (eds.) Methods of soil analysis. Agron 9, Part 2. Am. Soc. Agron.

- Madison, WI. Pp. 323-336.
- Bray, R. H. and L. T. Kurtz. 1945. Determination of total, organic, and available forms of phosphorus in soils. *Soil Sci.* 59:39-45.
- Burnett, E. and W. C. Moldenhauer. 1957. Using rainfall records as guides to predict yields of cotton on drylands of the High and Rolling Plains of Texas. TX. Ag. Exp. Sta. Bull. MP-233.
- Dahnke, W. C. 1971. Use of the nitrate specific ion electrode in soil testing. *Commun. Soil Sci. Plant Anal.* 2:73-84.
- Eck, H. V., V. L. Hauser, and R. H. Ford. 1965. Fertilizer needs for restoring productivity on Pullman silty clay loam after various degrees of removal. *Soil Sci. Soc. Am. Proc.* 29:209-213.
- Follett, R. F. and B. A. Stewart (eds.) 1985. Soil erosion and crop productivity. ASA, CSSA and SSSA Inc. Pub., Madison, WI 533 p.
- Fryrear, D. W. 1981. Long-term effect of erosion and cropping on soil productivity. *Geol. Soc. Am. Spec. Paper* 186. Pp. 253-259.
- Fryrear, D. W., A. Saleh, J. D. Bilbro, H. M. Schomberg, J. E. Stout, and T. M. Zobeck. 1998. Revised Wind Erosion Equation. USDA-ARS, Plant Stress and Water Conservation Research Laboratory Tech. Bull. No. 1.
- Fryrear, D. W., J. E. Stout, L. J. Hagen, and E. D. Vories. 1991. Wind erosion: Field measurements and analysis. *Trans. ASAE* 34:155-160.
- Hagen, L. J. 1991. A wind erosion prediction system to meet user needs. *J. Soil & Water Cons.* 46:106-111.
- Hagen, L. J. and L. Lyles. 1985. Amount and nutrient content of particles produced. *In* McCool, D. K., R.L. Bengtson, J. M. Gregory, C. K. Mutchler, C. W. Richardson, and J. M. Steichen. Erosion and soil productivity. ASAE Pub. 8-85. Pub by ASAE, St. Joseph, MI. 289 p.
- Lal, R. 1988. Monitoring soil erosion-s impact on soil productivity. *In* R. Lal (ed.) Soil erosion research methods. Soil & Water Cons. Soc. Ankeny, Iowa, pp. 187-200.
- Larney, F. J., M. S. Bullock, H. H. Janzen, B. H. Ellert, and E. C. S. Olson. 1998. Wind erosion effects on nutrient redistribution and soil productivity. *J. Soil and Water Cons.* 53:133-140.
- Larson, W. E, G. R. Foster, R. R. Allmaras, and C. M. Smith (eds.) 1990. Proceedings of soil erosion and productivity workshop. Pub. by Univ. of Minn., St. Paul. 142 p.
- Lyles, L. 1975. Possible effects of wind erosion on soil productivity. *J. Soil & Water Cons.* 30:279-283.
- McCool, D. K., R.L. Bengtson, J. M. Gregory, C. K. Mutchler, C. W. Richardson, and J. M. Steichen. 1985. Erosion and soil productivity. ASAE Pub. 8-85. Pub by ASAE, St. Joseph, MI. 289 p.
- NDSU. 1980. Chemical soil test procedures for the North Central Region. No. 499 Revised. Pp 14-15. North Dakota State University.
- Nelson D. W., and L. E. Sommers. 1982. Total carbon, organic carbon, and organic matter. *In* A. L. Page et. al., (eds.). Methods of soil analysis. Agron 9, Part 2. Am. Soc. Agron. Madison, WI. Pp. 539-579.
- SAS. 1990. Statistical analysis system, Version 6, SAS Institute Inc., Cary, NC
- Soil Survey Staff. 1998. Keys to soil taxonomy, Eighth Ed. USDA-NRCS, U.S. Govt.

- Printing Off., Washington, D. C.
- Soil Survey Division Staff. 1993. Soil survey manual. USDA Agric. Handbook No.18. U.S. Govt. Printing Off., Washington, D.C.
- Thomas, G. W. 1982. Exchangeable cations. *In* A. L. Page et. al., (eds.) Methods of Soil Analysis. Agron 9, Part 2. Am. Soc. Agron., Madison, WI. Pp. 159-165.
- Zobeck, T. M. And D. W. Fryrear. 1986a. Chemical and physical characteristics of windblown sediment. I. Quantities and physical characteristics. Trans. ASAE. 29:1032-1036.
- _____. 1986b. Chemical and physical characteristics of windblown sediment. II. Chemical characteristics and total soil and nutrient discharge. Trans. ASAE 29:1037-1041.
- Zobeck, T. M., D. W Fryrear, and R. D. Pettit. 1989. Management effects on wind-eroded sediment and plant nutrients. J. Soil & Water Cons. 44:160-163.